Variability and Trend Analysis of Temperature, Rainfall and Characteristics of Crop Growth Season in Eastern Zone of Tigray Region, Northern Ethiopia

Amdom Gebremedhin Berhe (amdomg@gmail.com)
Climate and society https://orcid.org/0000-0002-2617-1719
Solomon Habtu Misgna
Land Resource Management Environmental Protection
Girmay Gebre-Samuel Abraha
Land Resource Management Environmental Protection
Amanuel Zenebe Abraha
Climate and Society

Research

Keywords: climate variability, rainfall, temperature, trend analysis, crop growth characteristics, Eastern zone, Tigray, Ethiopia

Posted Date: May 11th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-474956/v1

Variability and trend analysis of temperature, rainfall and characteristics of crop growth season in Eastern zone of Tigray region, Northern Ethiopia

Amdom Gebremedhin[1*], Solomon Habtu[2], Girmay Gebre-Samuel[3], Amanuel Zenebe[4],

*Correspondence: amdomg@gmail.com
[1]Institute of Climate and Society, Mekelle University, Ethiopia
Full list of author information is available at the end of the article

Abstract

Background: Long term weather analyses are very useful indicators in determining future directions and in making adjustments required to existing systems. And, in order to favor farmers to adjust their farming practices, seasonal climate outlooks are needed. The main purpose of this manuscript was thus to analyze the variability and trends of maximum and minimum temperature, monthly and seasonal rainfall series and characteristics of crop growth season in Eastern zone of Tigray region over the period of 1980–2009.
Methods: Detail investigations were carried out using parametric (Linear regression) and non-parametric tests (Mankendall (Mk) and Sen's slope estimator). Moreover, homogeneity test using a method developed by Van Belle and Hughes was used for general trend analysis. In addition, daily rainfall data to characterize crop growth season were analysed using R-Instat and XLSTAT software for trend analysis.
Results: It was found that the general trend of monthly rainfall experienced an overall significant increasing trend. The seasonal rainfall experienced significantly increasing in summer main rainy season, June–September (*Kiremt*) while significantly decreasing in short rainy season, February–May (*Belg*). Likewise, the seasonal maximum temperature trends exhibited significant increase in each season while minimum temperature trend had inhomogeneous trend across seasons as well as stations. The trend of growing season characteristics (onset, cessation, LGP and dry spell length did not change significantly over the study period (1980–2009) in all stations. However, the coefficient of variability of LGP was (CV, >15%) and dry spell length was (CV, >25%) in association with short nature of LGP (68–85 days had a negative impact on the agricultural activities of the study area during the study period.
Conclusions: Despite significant increase of rainfall in summer season, the variability of rainfall and dry spell length was very large. Hence, the study recommends crop production in the study area demands appropriate adaptation strategies that considers the erratic nature of the rainfall, the long dry spell length in the season and increasing trends of temperature.

Key words: climate variability, rainfall, temperature, trend analysis, crop growth characteristics, Eastern zone, Tigray, Ethiopia

Background

Trends of temperature and precipitation, the two very important parameters for crop production, have been changing in Ethiopia along years. For the past four decades, Ethiopia's annual average temperature has been increasing by 0.37 ^{0}C per decade since 1951 (NMA 2007; Aragie 2013). Moreover, Ethiopia has experienced high degree of rainfall variability from year to year and season to season. The changes in temperature and rainfall patterns as a result of climate variability and change are very critical to the majority of the population of the country who are dependent on rain-fed agriculture for their livelihoods. The impacts of increased temperature and changes in rainfall patterns are expected to reduce crop production and water availability for irrigation and other farming uses, especially in the north, northeast and eastern lowlands of the country (Aragie 2013).

Most of the droughts caused by climate variability and change have been concentrated in the eastern and southern part of Tigray region (Gebrehiwot and van der Veen 2013). The climate of the study area, located in the Eastern part of Tigray region in northern Ethiopia, is characterized by frequent droughts. Almost every year, localized droughts associated with variable and erratic rainfall have been causing for crop failure and jeopardizing the livelihood and development activities (Awulachew et al. 2011; Gebrehiwot and Van der Veen 2013). Indeed, moisture stress stands to be the major limiting factor for crop and animal production in the Easter zone of the Tigray region (Meles et al. 1997). As a result of this, especially crop yield has been severely affected during part of its growing period (Araya and Stroosnijder 2010).

Albeit the fact that rainfall variability and associated localized droughts have been the greatest concern in the study area, little attempts have been made so far to quantify the spatio-temporal characteristics of precipitation and temperature. Yet, the emphasis of most of the studies related to the trend analysis so far carried out in Tigray region have been limited to rainfall analysis. And, temperature analysis has been ignored in many of these studies, although it is also vital for crop production and water related issues.

Moreover, the rainfall analyses made by majority of the studies were restricted to even trends of annual or monthly total values (Abraha 2015; Meze-Hausken 2004; Gebrehiwot et al 2011; Gebrehiwot and van der Veen 2013; Hayelom et al 2017). Rainfall variability based on agricultural practices such as onset and cessation at interval of days, length of growing period (LGP), and wet and dry spells weren't included in those studies with the only exception that Araya et al. (2010) has determined LGP of two crops of Teff (Eragrostis tef) and barley (Hordeum vulgare) in Giba catchment in Tigray region using historical climate data. Yet, the rainfall and rainy season characteristics are important to make proper crop-based decisions in seeding, fertilizing, selecting crop variety, selecting suitable cropping pattern, and selecting best agro-techniques. Assessing long-term trends of rainfall and rainy season characteristics (including onset, cessation and LGP) can help to formulate farming strategies to efficiently use the available water (Fiwa et al. 2014). Rainfall statistics for dry spells are also very important for planning and management of water resources (Almazroui et al. 2017).

Overall, assessing spatio-temporal analysis of changes in temperature & rainfall, and rainfall characteristics which was the main purpose of this research would thus help to better understand the uncertainties associated with rainfall and temperature patterns and will favor knowledge based management of agriculture, irrigation and other water related sectors in the study area.

Materials and methods

Description of the study area

Eastern zone, the study area, is bordered on the east by the Afar Region, on the south by South Eastern zone of Tigray, on the west by central zone of Tigray and on the north by Eritrea. Its geographical location is between $13^{0}33'2"$ - $14^{0}40'54"$ latitude and $39^{0}11'39"$ - $39^{0}59'11"$ longitude (Figure 1). The zone has an area of 561,000 ha and seven districts (Erob, Hawzen, Wukro, Atsbi-Womberta, Ganta-Afeshum, Gulo-Mekeda and Saesie-TsaedaEmba). The altitude ranges between 1500-3280 meter above sea level (masl). The zone is characterized by three traditional agro-ecologies of highland (>2300 masl), midland (1500-2300 masl) and lowland (<1500 masl).

Three watersheds, namely Agulae, Suluh and Genfel were selected from the zone for this research purpose based on population growth, urbanization, and availability of small-scale irrigation schemes in each watershed (Figure 1).

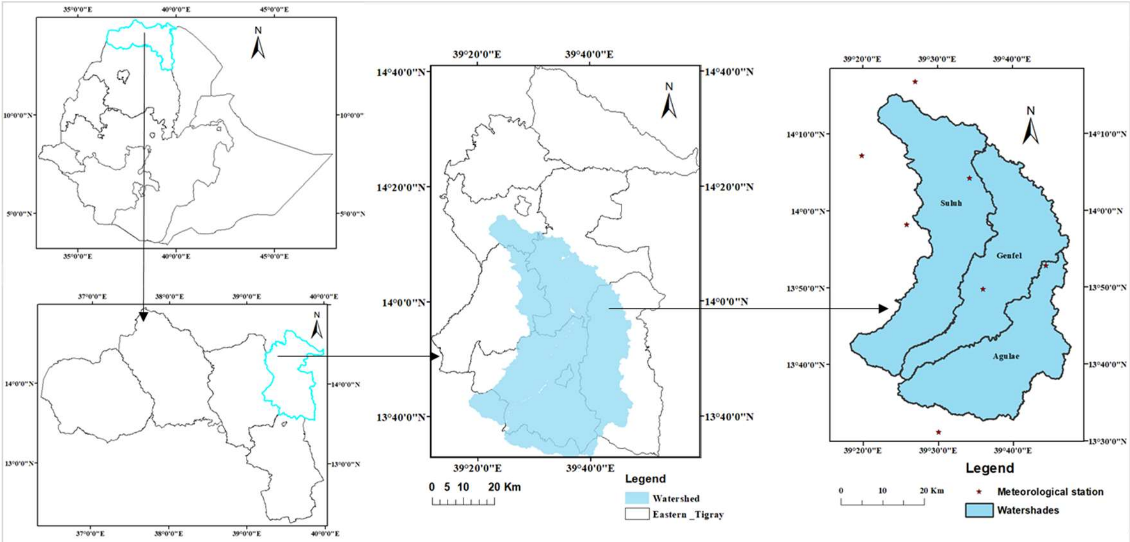

Figure 1: Location of the study area and selected watersheds

Data used

30 years of climate data (rainfall and temperatures) from seven stations within and nearby of the Eastern zone of Tigray region from 1980-2009 were collected from Enhancing National Climate Services Initiative (ENACTS) recently implemented at Ethiopian National Meteorological Agency (NMA). Through this initiative (ENACTS) the availability of climate data is improved by combining careful quality control of data from weather stations with that of satellite estimates. The combined data set is generated at a 10-daily time scale and for every 4 km grid across Ethiopia. This is the best available dataset for the country which is homogeneous and recommended for climate analysis (Dinku et al. 2014). The detail information about ENACTS is elucidated in Dinku et al. (2014) and Dinku et al. (2018). The stations together along with their geographical locations and elevations are shown in (Table 1).

Table 1:Geographical location of the meteorological stations

Station	Latitude (DD)	Longitude (DD)	Elevation (meter)
Illala	13.52	39.50	2012
Adigrat	14.28	39.45	2470
Edagahamus	14.12	39.33	2700
Atsbi	13.88	39.74	2600
Sinkata	14.07	39.57	2480
Wukro	13.83	39.60	1995
Hawzen	13.97	39.43	2255

Data analysis

To identify linear and non-linear trends in monthly, annual and seasonal time scales of rainfall and temperature series, both parametric (linear regression) and non-parametric (Mann-Kendall and Sen's estimator of slope) statistical tests were considered. For abrupt change detection Pettitt (Mann-Whitney U-test) and for homogeneity test of data the Van Belle and Hughes were also utilized.

Linear regression

A straight line is fitted to the data to determine whether the slope is different from zero or not. Simple linear regression method was used to determine the tendency (1). Student t-test was applied to determine the statically significance of the trend at 5% significant level.

$$Y = ax + b \tag{1}$$

Where: Y is dependent variable, a is the slope, x is independent variable and b is the intercept.

The parametric test is commonly applied to normal data. Hence, before analysis, the rainfall and temperature data are tested for normality using Shapiro-Wilk test. Shapiro-Wilk statistical test was widely used in several studies to test for normality of data (De Lima et al. 2010; Machiwal and Jha 2008; Muchuru et al. 2016; Suryadi and Sugianto 2018) and recommended for normality test as it provides better estimates, for example as compared to Kilmogorov-Smirnov method (Aura et al. 2019).

Mann-Kendall and Theil-Sen's Slope estimator

Monthly, seasonal and annual trends were assessed using Mann-Kendall trend test (Mann 1945; Kendall 1975) and Sen´s slope estimator (Sen 1968) (2-5). The Mann-Kendall test and Sen's slope estimator are two non-parametric tests and widely applied in various trend detection studies (Chattopadhyay and Edwards 2016; Asfaw et al. 2017; Hamza et al. 2017; Palaniswami and Muthiah 2018; Samo et al. 2017).

Mann-Kendall test

The Mann-Kendall test S of the series X was calculated by applying equation 2 and 3 (Mann 1945; Kendall 1975):

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn(X_j - X_i) \tag{2}$$

$$sgn(X_j - X_i) = \begin{cases} +1 \ if \ (X_j - X_i) > 0 \\ 0 \ \ if \ \ (X_j - X_i) = 0 \\ -1 \ if \ (X_j - X_i) < 0 \end{cases} \tag{3}$$

Where, sgn (X_j-X_i) is the signum function, X_i ranked from i = 1, 2…N–1 and X_j ranked from j = i+1, 2…N. Each data point X_i is used as a reference point and is compared with all other data points X_j values.

The Mann-Kendal test statistics (S) represents asymptotically normal distribution and give the mean of zero and the variance of one (Mann 1945; Kendall 1975).

The variance associated with S is calculated by applying equation 4:

$$Var\ (S) = \frac{1}{18}\left[N(N-1)(2N+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)\right] \tag{4}$$

Where: m is the number of tied groups and t_i is the number of data points in group i

The standardized test statistic Z(S) is calculated by applying equation 5 (Mann 1945; Kendall 1975).

$$Z(S) = \begin{cases} \dfrac{S-1}{\sqrt{Var\ (S)}} \ if \ S > 0 \\ 0 \qquad\qquad if \ S = 0 \\ \dfrac{S+1}{\sqrt{Var\ (S)}} \ if \ S < 0 \end{cases} \tag{5}$$

The H_o (null hypothesis) is rejected, if absolute value of Z(S) is greater than $Z_{critical}$ ($Z_{\alpha/2}$), in which α represents the level of significant. Positive values of normalized test statistics Z(S) indicate an increasing trend and negative Z values indicate decreasing trends. In this study, statistically significant level at 95% confidence level (at α = 0.05) was used.

Theil-Sen's Slope estimator

This method is used to quantify the linear trend in time series analysis. The slope ϴi between two values in a time series X is estimated by equation 6:

$$\Theta i = \frac{X_k - X_j}{k - j}\ , k \neq j \quad , \qquad where\ i = 1, 2, \ldots . N \tag{6}$$

Where X_k and X_j are data values at times k and j (K>J)

The median of these N values of Θi is known as Sen's estimator of slope and calculated by equation 7. The positive sign of Θ_{median} represents an increasing trend while negative sign shows a decreasing trend.

$$\Theta_{\text{median}} = \begin{cases} \Theta_{\frac{(N+1)}{2}}, & N\ odd \\ \dfrac{\Theta_{\frac{N}{2}} + \Theta_{\frac{(N+1)}{2}}}{2}, & N\ even \end{cases} \tag{7}$$

Van Belle and Huges' homogeneity of trend tests

To test homogeneity of trends, the most widely used Van Belle and Hughes (Belle and Hughes 1984) test was used. This provides single statistics which indicates whether the months/seasons are behaving in similar (homogeneous) fashion or different (heterogeneous) from each other. This test uses Z-values (standardized test statistics (Z(S)) from MK-test statistics for each station.

To get the trend homogeneity of temperature and rainfall at multiple stations, Van Belle and Hughes proposed a procedure based on the partitioning of the sum of squares. The analysis procedure uses chi-square (X^2) test statistics of various chi-squares (X^2 homogeneous, X^2 month/season, X^2 station, X^2 month/season-station interaction) for testing the trend homogeneity. The null hypothesis of the homogeneity test stated that there is no trend for a particular month or season in a given station. The formulas from 10-15 were used to test the homogeneity of the trends by partitioning the X^2_{total} in to respective source of variations.

1. X^2_{total}

$$X^2_{total} = \sum_{i=1}^{K} \sum_{m=1}^{M} Z^2_{im} \tag{10}$$

Where: K is the number of month or seasons, M is the number of stations and Z is the standardized test statistics with KM d.f.

2. Test for significant of common trend (X^2_{trend})

$$X^2_{trend} = KM\,\bar{Z}^2 \tag{11}$$

Where: K is the number of month or seasons and M is the number of stations and, $\bar{Z}^2$ is the average square of standardized test statistics with 1 d.f.

3. Homogeneity trend test at different stations in different months/seasons ($X^2_{homogeneous}$)

$$X^2_{homogeneous} = X^2_{total} - X^2_{trend} = \sum_{i=1}^{k} (Z_i)^2 - k\,(\bar{Z})^2 \qquad (12)$$

The values of Z_i and $\bar{Z}$ are calculated as:

$$Z_i = \frac{S_i}{\sqrt{Var\,(S_i)}} \quad and\ \bar{Z} = \frac{1}{k}\sum_{i=1}^{k} Z_i$$

Where: S_i is the Mann-Kendall statistic for month i, and k= 12 for monthly data values, with (KM-1) d.f.

4. Test for monthly or seasonal heterogeneity ($X^2_{month/season}$)

$$X^2_{mon\ \ /season} = M.\sum_{i=1}^{k} (\bar{Z}_{iM})^2 - X^2_{trend} \qquad (13)$$

Where: M is the number of stations with (K-1) d.f.

5. Test for station heterogeneity ($X^2_{station}$)

$$X^2_{station} = K.\sum_{i=1}^{M} (\bar{Z}_{kM})^2 - X^2_{trend} \qquad (14)$$

Where: K is the number of month/season and with (M-1) d.f.

6. Test for the interaction ($X^2_{month/season-station}$)

$$X^2_{month/season-stat} = X^2_{homogeneou} - X^2_{month\ or\ season} - X^2_{station} \qquad (15)$$

Crop risk assessments

In this study, crop risks associated with the extreme events like dry spells and other growing season characteristics (Onset, Cessation and Length of Growing Period (LGP)) was considered for the analysis using R-Instat (V.0.6.2) software (http://www.r-instat.org/Download). Growth season characteristics such as onset and cessation date, Length of Growing Period (LGP), and dry spell length were determined using 30 years of data in seven stations. Specific rainfall characteristics information is vital for crop planning and for carrying out agricultural operations. These are important to make crop-based decisions during seeding, fertilizing, selecting crop variety, selecting suitable cropping pattern, and selecting best agro techniques, etc.

Onset and cessation date: The onset of rainy season in Eastern zone of Tigray region was assumed to start as of June 19 when there occur wet spells of at least three consecutive days totaling 20 mm or more provided that there was no dry spell longer than 7 or more days within 30 days. Moreover, cessation date was assumed as the date when the stored soil moisture reaches 100 mm after rainfall falls below ET_o values as per Higgins and Kassam (1981), which considers annual crops utilize 75-100 mm sored soil moisture during their harvest stage. The possible onset day was selected based on the information collected from farmers during field survey. A minimum threshold value of rainfall (<1mm) was considered as part of dry spell, which is insignificant amount for crop use (Siva Kumar 1992).

Length of Growing Period (LGP): The duration between the onset of rain season (OS) and cessation of total seasonal rainfall (CS) represent the number of rainy days or length of growing season (16).

$$LGP = CS - OS \tag{16}$$

Where: LGP is Length of Growing Season, CS is Cessation season rainfall and OS is onset season rainfall

Dry spell length: is a time period with no rain or less than 0.1mm rain for more than 7 days within 30 days. The average value of the dry spells was computed at seasonal time scale during the main rainy season.

Results and Discussion

Annual and seasonal rainfall variability

The total rainfall amount throughout the study area was found to be above 550 mm per annum. A minimum total rainfall amount of 554 mm was recorded in Edagahamus station while a maximum total amount of 617 mm was obtained in Hawzen station (Table 2). The contribution of *Kiremt* season to that of the annual total rainfall amount is very large in all stations. It varied from 54–84%. In addition, the contribution of the *Belg* season was not to be underestimated. In the majority of the stations it contributed to more than 25% of the total rainfall. The *Belg* season is very useful for long cycle crops. The long cycle crops are planted during this season before *Kirem*t. Moreover, farmers also used this season for land management practices, such as repeated plowing and in-situ soil moisture conservation activities.

However, the coefficient of variability (CV) of the total rainfall amount was much higher for *Belg* season that ranged from 37–45% than Kiremt season rainfall that ranged from 21–31% and indicating very higher temporal variability of the seasons (Table 2). Several studies also showed that the CV of *Belg* season is higher than *Kiremt* season in northern Ethiopia (Hadgu et al. 2013; Kiros et al. 2017; Weldesenbet 2019). Of all stations, Hawzen station showed the highest both *Kiremt* and *Belg* inter annual variability (CV, 31% and 45%, respectively). In general, the variability of the seasonal total rainfall in the study area can be categorized from moderate to high variability. Previous studies on their respective study areas reported that the annual and seasonal rainfall variability showed moderate and high inter annual variability (Ademe et al. 2020; Ayalew et al. 2012; Bewket and Conway 2007; Hadgu et al. 2013).

Table 2: Descriptive statistics of annual and seasonal (Kiremt and Belg) variables

	Variables	Annual	Kiremt	Belg
Ilalla	Contribution to annual mean, mm	569	392 (69%)	139 (24%)
	Std. deviation	93	83	56
	CV (%)	16	21	41
Edagahamus	Contribution to annual mean, mm	554	298 (54%)	195 (35%)
	Std. deviation	89	67	75
	CV (%)	16	22	38
Adigrat	Contribution to annual mean, mm	575	348 (61%)	179 (31%)
	Std. deviation	105	96	73
	CV (%)	18	28	41
Sinkata	Contribution to annual mean, mm	573	353 (62%)	167 (29%)
	Std. deviation	80	75	62
	CV (%)	14	21	37
Wukro	Contribution to annual mean, mm	556	387 (70%)	136 (25%)
	Std. deviation	104	100	58
	CV (%)	19	26	42
Atsbi	Contribution to annual mean, mm	560	375 (67%)	148 (26%)
	Std. deviation	105	99	65
	CV (%)	19	26	44
Hawzen	Contribution to annual mean, mm	617	519 (84%)	91(15%)
	Std. deviation	152	162	41
	CV (%)	25	31	45

Trend analysis of Rainfall and Temperature

Monthly rainfall trend

The two tailed MK and LR monthly rainfall statistical tests showed increasing positive trend in all stations (Table 3). The magnitude of change is indicated by the Sen's slope estimator that ranges from 0.29–0.99 mm/month for June, 0.27–2.51 mm/month for July, 0.82–2.96 mm/month for August and 0.22–0.55 mm/month for September. Nevertheless, June and July showed statistically significant increasing trends in 3 of 7 stations and 4 of 7 stations at $p = 0.1$, respectively and each month showed significant in only Hawzen station at $p = 0.05$ level. September showed significant increasing trend only in Edagahamus station at $p = 0.1$ level and other 2 of 7 stations (Sinkata and Wukro) at $p = 0.05$ level. August month showed statistically non-significant increasing trends in all stations.

Table 3: Monthly rainfall (June–September) MK and LR statistical test values

Rainfall			**Stations**					
Months	**Statistics**	**Illala**	**Edagahamus**	**Adigrat**	**Sinkata**	**Wukro**	**Atsbi**	**Hawzen**
June	LR (t-test)	NN	NN	NN	NN	NN	NN	NN
	MK (z-test)	1.75***	1.71***	1.25	1.32	1.61	1.78***	2.00**
	Sen's slope estimate	0.52	0.38	0.30	0.29	0.34	0.31	0.99
	Sen's slope (95% CI)	0.4-0.7	0.3-0.5	0.2-0.4	0.2-0.4	0.2-0.4	0.3-0.4	0.8-1.1
July	LR (t-test)	NN	NN	NN	NN	NN	NN	NN
	MK (z-test)	1.82***	0.39	1.82***	1.68***	1.64***	1.03	2.07**
	Sen's slope estimate	1.16	0.27	1.30	1.29	1.55	1.07	2.51
	Sen's slope (95% CI)	1.0-1.6	0.03-0.6	1.1-1.5	1.0-1.7	1.3-1.8	0.8-1.6	2.1-2.8
August	LR (t-test)	0.76	1.21	1.72	1.01	1.62	1.87	1.29
	MK (z-test)	0.54	1.03	1.36	0.89	1.43	1.57	1.53
	Sen's slope estimate	0.82	1.17	2.04	1.00	2.26	2.27	2.96
	Sen's slope (95% CI)	0.5-1.3	0.8-1.7	1.4-2.5	0.5-1.7	1.7-2.8	1.8-2.8	2.2-3.5
September	LR (t-test)	0.89	1.95***	1.40	2.10**	2.20**	1.52	0.44
	MK (z-test)	0.89	1.82***	1.14	1.96**	2.07**	1.53	0.71
	Sen's slope estimate	0.22	0.22	0.26	0.31	0.55	0.52	0.27
	Sen's slope (95% CI)	0.1-0.3	0.2-0.3	0.2-0.4	0.3-0.34	0.4-0.6	0.4-0.6	0.2-0.5

NN-Non-normal data ** Statistically significant at 5% significance level, *** Statistically significant at 10% significance level

Seasonal rainfall, maximum and minimum temperature trends

Table 4 and 5 showed seasonal trends of rainfall, maximum and minimum temperatures. The values obtained from the LR-test statistics are higher than those values obtained from MK-test in the majority of the stations for all variables. Nevertheless, the significance and the trend direction results obtained from LR test are in line with those obtained from MK test in all incidences.

Annual rainfall showed positive increasing trend in most of the stations except in Edagahamus. In addition, *Kiremt* season rainfall values also showed increasing positive trend whilst *Belg* season showed a decreasing trend in all stations (Table 4).

The trend of total rainfall showed an increasing trend and varied from 0.8–5.51 mm/year for annual rainfall, from 2.34–6.78 mm/season for *Kiremt* and decreasing trend from 0.74–2.29 mm/season for *Belg*. However, annual and seasonal trends are insignificant at 5% significant level. Our results corroborate the findings of previous studies that indicated non-significant rainfall trend in northern

Ethiopia (Cheung et al 2008; Seleshi and Camberlin 2006; Seleshi and Zanke 2004; Viste et al 2012).

Of all stations, Hawzen showed the highest increasing trend magnitude of annual (5.51 mm/year) and *Kiremt* (6.78 mm/season) rainfall totals. And, Edagahamus station showed the highest decreasing trend magnitude of *Belg* rainfall season (2.29 mm/season). Few stations (Adigrat, Sinkata and Wukro) showed significant increasing *Kiremt* rainfall and significant decreasing *Belg* rainfall (Edagahamus) at $p = 0.1$ level.

Table 4: Seasonal rainfall statistical trend values

			Stations					
Rainfall (mm)	**Statistics**	**Illala**	**Edagahamus**	**Adigrat**	**Sinkata**	**Wukro**	**Atsbi**	**Hawzen**
Annual	LR (t-test)	0.47	-0.11	0.93	0.73	1.40	1.42	1.25
	MK (z-test)	0.32	-0.25	0.86	0.64	1.43	1.50	1.43
	Sen slope estimate	0.8	-0.82	2.12	1.3	3.12	3.24	5.51
	Sen's slope (95% CI)	-0.1-1.7	-1.4-0.4	1.3-3.2	0.6-1.8	2.2-3.9	2.4-3.6	3.9-6.7
Kiremt	LR (t-test)	1.28	1.36	1.75	1.69***	1.85***	1.86***	1.46
	MK (z-test)	1.14	1.61	1.53	1.78***	1.64***	1.78***	1.61
	Sen slope estimate	2.34	2.38	3.19	2.93	3.97	3.61	6.78
	Sen's slope (95% CI)	1.6-2.9	1.8-2.7	2.8-4.2	2.5-3.2	2.9-5.1	3.2-4.3	6.0-7.6
Belg	LR (t-test)	-1.13	NN	NN	NN	NN	NN	NN
	MK (z-test)	-1.07	-1.89***	-1.57	-1.32	-1.03	-1.18	-1.07
	Sen slope estimate	-1.27	-2.29	-1.94	-1.67	-0.84	-1.05	-0.74
	Sen's slope (95% CI)	-1.7-(-1)	-2.8-(-2.1)	-2.4-(-1.5)	-1.9-(-1.2)	-1.2-(-0.4)	-1.4-(-0.7)	-1.1-(-0.4)

NN-Non-normal data, ** Statistically significant at 5% significance level, *** Statistically significant at 10% significance level

The seasonal temperature exhibited different trend directions (Table 5). Significantly increased warming trend of maximum and minimum temperature values (0.04–0.07^{o}C/year, 0.024–0.06^{o}C/year) and (0.07–0.1^{o}C/season, 0.06–0.12^{o}C/season) were exhibited for annual and *Belg* season in all stations, respectively at $p = 0.01$ level.

Unlike annual and *Belg* season, the maximum and minimum *Kiremt* season temperature showed increasing and decreasing trend directions. In most of the stations (in 5 of 7 stations), such as in Illala, Edagahamus, Adigrat, Sinkata and Hawzen, the maximum temperature showed an increasing trend whereas in Wukro and Atsbi stations it showed a decreasing trend.

In the case of minimum *Kiremt* temperature a decreasing trend was observed in most of the stations (in 6 of 7 stations) except in Edagahamus station. Yet, the Kiremt season maximum and minimum temperatures trends were not significant at 5% significant level in most of the stations. Few stations such as Edagahamus and Hawzen showed significant increasing maximum temperature by 0.08°C/season, at $p = 0.01$ level and 0.02°C/season, at $p = 0.1$ level, respectively. Moreover, Adigrat and Hawzen stations showed a significant decreasing minimum temperature by 0.04°C/season at $p= 0.01$ level and 0.03 °C/season at $p = 0.1$ level, respectively.

Table 5:Seasonal maximum and minimum temperature statistical trend values

		Stations						
T_{max} (°C)	**Statistics**	**Illala**	**Edagahamus**	**Adigrat**	**Sinkata**	**Wukro**	**Atsbi**	**Hawzen**
Annual	LR (t-test)	6.91*	6.47*	5.75*	5.99*	5.91*	5.58*	7.55*
	MK (z-test)	4.85*	4.53*	4.32*	4.85*	4.32*	4.57*	5.07*
	Sen slope estimate	0.05	0.07	0.05	0.05	0.044	0.048	0.052
	Sen’s slope (95% CI)	0.05-0.06	0.07-0.08	0.047-0.05	0.051-0.06	0.04-0.05	0.046-0.049	0.05-0.056
Kiremt	LR (t-test)	1.13	4.56*	0.84	0.92	-0.13	-0.17	1.85***
	MK (z-test)	1.25	3.32*	0.43	1.25	0.00	-0.32	1.86***
	Sen slope estimate	0.02	0.08	0.004	0.015	-0.0007	-0.002	0.022
	Sen’s slope (95% CI)	0.01-0.023	0.07-0.09	0.0-0.012	0.01-0.02	-0.01-0.01	-0.01-0.00	0.02-0.03
Belg	LR (t-test)	6.12*	3.46*	4.53*	5.07*	5.18*	6.14*	4.38*
	MK (z-test)	4.42*	2.89*	3.57*	4.42*	3.60*	4.39*	3.35*
	Sen slope estimate	0.09	0.08	0.07	0.09	0.083	0.108	0.068
	Sen’s slope (95% CI)	0.09-0.1	0.07-0.09	0.065-0.08	0.09-0.097	0.08-0.09	0.1-0.11	0.06-0.08
T_{min} (°C)	**Statistics**	**Illala**	**Edagahamus**	**Adigrat**	**Sinkata**	**Wukro**	**Atsbi**	**Hawzen**
Annual	LR (t-test)	7.86*	3.27*	2.16*	7.88*	6.83*	5.43*	5.62*
	MK (z-test)	4.75*	2.82*	1.89***	5.35*	4.60*	4.10*	3.93*
	Sen slope estimate	0.063	0.05	0.024	0.053	0.055	0.046	0.047
	Sen’s slope (95% CI)	0.06-0.07	0.04-0.06	0.02-0.03	0.05-0.06	0.05-0.06	0.042-0.05	0.04-0.05
Kiremt	LR (t-test)	-0.09	1.17	-3.35*	-0.26	-1.52	-1.63	-2.42***
	MK (z-test)	0.00	0.79	-2.89*	-0.46	-1.39	-1.18	-1.93***
	Sen slope estimate	-0.0005	0.01	-0.04	-0.01	-0.02	-0.02	-0.033
	Sen’s slope (95% CI)	-0.004-0.01	0.01-0.02	-0.05-(-0.04)	-0.01-(-0.001)	-0.03-(-0.02)	-0.03-(-0.013)	-0.04-(-0.03)
Belg	LR (t-test)	8.56*	2.78*	5.89*	9.82*	12.28*	8.86*	8.68*
	MK (z-test)	5.00*	1.93*	4.42*	5.67*	6.17*	5.17*	5.14*
	Sen slope estimate	0.1	0.057	0.088	0.1	0.117	0.089	0.098
	Sen’s slope (95% CI)	0.09-0.11	0.05-0.07	0.08-0.09	0.098-0.1	0.1-0.12	0.084-0.094	0.09-0.1

NN-Non-Normal data, *Statistically significant at 1% significance level, ** Statistically significant at 5% significance level, *** Statistically significant at 10% significance level

Test of homogeneity of trends

Monthly and seasonal rainfall homogeneity

During homogeneity test, four possible scenarios were examined based on Van Belle and Hughes (1984):

(i) When all values of X^2 for stations, X^2 months/X^2 seasons, and the interactions are non-significant

(ii) When values of X^2 months/X^2 seasons is significant and X^2 values of stations is non-significant, different trend direction of each months/seasons was tested using $M\bar{Z}_k^2$, (i = 1,2, …, K)

(iii) When X^2 values of stations is significant and X^2 months/X^2 seasons is non-significant , different trend directions at each station was tested using $K\bar{Z}_m^2$, (m = 1,2, … , M), and

(iv) When both months/seasons and stations or the interactions are significant, the only meaningful trend test was possible for individual month/season-station using Z_{im}, (i = 1, 2, …, K; m = 1, 2, …, M).

In the monthly rainfall series (June–September), none of the station, season and station-season interaction components exhibited significant trend heterogeneity since X^2 station, X^2 month, and the interaction are less than the X^2 critical values (Table 6). But, the overall trend heterogeneity was found to be significant since X^2 trend > X^2 critical. The average of Mann-Kendall test statistics over months (k=1, 2, 3, 4) and stations (m= 1, 2,….7) was found to be positive ($\bar{Z}_{.}$= 1.44) indicating an increasing trend.

However, in seasonal (annual, *Belg* and *Kiremt*) rainfall series X^2 season only exhibited seasonal heterogeneity of rainfall trend since X^2 season is greater than X^2 critical values. But, the stations were found to have homogeneous trends (Table 8). Hence, according to scenario (ii) trend direction analysis at each season using K seasonal statistics becomes necessary while each season refers to the value of X^2 critical (with d.f.=1, i.e., 6.64) at 1% significant level. In evaluating the various homogeneity test it is best to use high significance level to obtain the same Z statistical sign by neglect small differences in the trend magnitude not seem too important (Belle and Huges, 1984).

Significance of trend homogeneity for each season was tested using the average Mann-Kendal test statistics (Z_k). Here, $M\bar{Z}_k^2$ was obtained to test the overall seasonal trend homogeneity. Accordingly, the K seasonal statistics $M\bar{Z}_k^2$ becomes less than the X^2 critical for annual and greater than for *Kiremt* and *Belg* seasons (Table 8). As a result, despite previous studies do not show any clear signs of changing rainfall pattern in north Ethiopia (Viste et al 2012; Seleshi and Zanke 2004; Seleshi and Camberlin 2006; Cheung et al 2008), the Van Belle and Huges for general trend test indicated that the annual rainfall did not increase significantly while *Kiremt* increased significantly and *Belg* rainfall decreased significantly in Easter zone of Tigray region in Northern Ethiopia.

Table 6: Significance test of trend homogeneity for monthly rainfall (June-September)

Source	X^2 value	d.f.	X^2 critical, at 5%	X^2 critical, at 1%	Sign.
Total	63.67	K.M=4*7=28	41.34	48.28	-
Homogeneous	5.71	K.M-1=28-1=27	40.11	46.96	-
Month	0.70	K-1=4-1=3	7.82	11.35	
Station	0.64	M-1=7-1=6	12.59	16.8	
Month-Station	4.36	(K-1)*(M-1)=18	28.87	34.81	
Monthly homogeneity		X^2 months< X^2 critical			NS
Station homogeneity		X^2 station< X^2 critical			NS
Interaction		X^2 months-station< X^2 critical			NS
Trend	57.96	1=1	3.8	6.64	S
Global trend		X^2 trend> X^2 critical			Trend

Sign.: Significance; NS: not significant; S: significant; d.f.: degrees of freedom

Table 7: Significance test of trend homogeneity for seasonal rainfall (Annual, Kiremt, Belg)

Source	X^2 value	d.f.	X^2 critical, at 5%	X^2 critical, at 1%	Sig.
Total	38.04	21	32.67	38.93	-
Homogeneous	35.08	20	31.41	37.57	-
Season	31.56	2	5.99	9.21	
Station	1.96	6	12.59	16.81	
Season-Station	1.56	12	21.03	26.22	
Seasonal homogeneity		X^2 seasons> X^2 critical			S
Station homogeneity		X^2 station<X^2 critical			NS
Interaction		X^2 seasons-station< X^2 critical			NS
X^2 trend	2.96	1	3.8	6.64	Not used

Sign.: Significance; NS: not significant; S: significant; d.f.: degrees of freedom

Table 8: Seasonal rainfall trend test result for the stations

Season	$\bar{Z}_K$	$\bar{Z}_k^2$	$M\bar{Z}_k^2$	Significance
Annual	0.85	0.72	5.01	NS
Kiremt	1.59	2.51	17.59	S
Belg	-1.30	1.70	11.92	S

Maximum and Minimum temperature homogeneity

Van Belle and Hugest tests were similarly applied to examine changes in trends of maximum and minimum temperature series in all of the selected stations.

The value of X^2 season for maximum and minimum temperature was significant implying heterogeneous while the value of X^2 station for maximum and minimum temperature was non-significant implying homogeneous (Table 9). According to scenario (ii), testing trend direction at each season using K seasonal statistics becomes necessary (Table 10 and 11).

Table 10 and 11 indicated that the computed $M\bar{Z}_k^2$ values for season were found to be greater than the critical X^2 (equal to 6.64) with d.f. = 1 at 1% significance level. Hence, the annual, *Belg* and *Kiremt* maximum temperature increased significantly (Table 10). Similarly, annual and *Belg* minimum temperature increased significantly while *Kiremt* decreased significantly (Table 11).

The trends in minimum temperature in different seasons were not homogeneous in the study area as the trends in *Kiremt* were different from annual and *Belg*. It is also noticeable that in 6 of 7 stations had negative trends in the season of *Kiremt*, while all stations experienced positive trends in annual and *Belg* season.

Table 9: Maximum and Minimum temperature homogeneity test statistics

Sources	Maximum Temperature					Minimum Temperature				
	X^2 - value	d.f.	X^2 critical, at 5%	X^2 critical, at 1%	Sign.	X^2 - value	d.f.	X^2 critical, at 5%	X^2 critical, at 1%	Sign.
Total	273.05	21	32.67	38.93	-	304.05	21	32.67	38.93	-
Homogeneous	59.67	20	35.17	37.57	-	165.81	20	35.17	37.57	-
Seasons	47.71	2	5.99	9.21	S	136.83	2	5.99	9.21	S
Station	2.96	6	12.59	16.81	NS	12.88	6	12.59	16.81	NS@1%
Season-Station	9.00	12	21.03	26.22	NS	16.10	12	21.03	26.22	NS
Trend	213.38	1	3.84	6.64	Not used	138.24	1	3.84	6.64	Not used

Sign.: Significance; NS: not significant; S: significant; d.f.: degrees of freedom

Table 10: Seasonal maximum temperature homogeneity test statistics

	$\bar{Z}_K$	$\bar{Z}_k^2$	$M\bar{Z}_k^2$	Sign.
Annual	4.64	21.56	150.95	S
Kiremt	1.11	1.23	8.64	S

Belg	3.81	14.50	101.49	S

Table 11: Seasonal minimum temperature homogeneity test statistics

	$\bar{Z}_K$	$\bar{Z}_k^2$	$M\bar{Z}_k^2$	Sign.
Annual	3.92	15.37	107.56	S
Kiremt	-1.01	1.02	7.13	S
Belg	4.79	22.91	160.37	S

Trends of crop growing season characteristics

Daily rainfall (1980-2009) obtained from seven meteorological stations were used to analyze the trends of onset, cessation, length of growing period (LGP) and dry spell length. The generated values of characteristics of crop growth season are presented in Table 12 that shows mean, Mann Kendall's-tau, and Sen's slope estimator at 5% significant level values.

The 30-years median early onset date of the Kiremt season was ranged from 30-June/ 182.5 DOY (Day of Year) at Hawzen to 8-July/190 DOY at Wukro. The onset dates of Ilalla, Adigrat, Edagahamus, Wukro and Atsbi are very close to Hawzen station. The onset date variability was lower (CV<10%) at all stations. The median cessation date indicated a wide range of dates among the stations. The earliest cessation was on 11-Sep./255 DOY at Edagahamus and late cessation was on 25-Sep/269 DOY at Hawzen. As compared to the onset date, cessation variability was very low (<5%) at all stations. The CV of onset and cessation periods is (<10%) indicates very small, possibly relatively stable onset and cessation. And, this is very advantageous for the farmers in searching other off farm activities once they have stabilized onset and cessation dates.

Table 12 also showed the time series of LGP for different stations. There is a general increasing trend, following the general early in onset and delay in the cessation date. Median LGP values in the study area varied from 68 days at Edagahamus to 85 days at Hawzen. Different researcher using different criterions for onset and cessation analysis indicated that the LGP of the north eastern stations ranged from 60-100 days (Berhe 2011; Gebre et al. 2013). The CV in LGP was larger than 15% in all stations indicating that crop growing season are relatively unstable and how risk is to relay on one type of crop in the study area. This kind of information is very critical in selecting crop cultivars that can grow based on their maturity.

Similarly, the mean seasonal dry spell length was ranged from 24 days at Adigrat to 30 days at Edagahamus. The dry spell length was very variable with CV that ranged from 25-43%. This indicates the high risk of intra-seasonal water deficit situation in the study area. These findings are in agreement with those of Gebreselassie and Moges (2016) who analysed the spatial and variability patterns of dry spell length of daily rainfall from 24 stations in Tekeze basin (Ethiopia), and found that the north-eastern stations showed very large and greater than 30% variability. The highest variability of dry spell length was at Illala while the lowest was at Edagahamus.

Table 12: Statistical values and trends of onset, cessation, LGP and dry spell length

Characteristics of crop growth	Statistics	Stations						
		Illala	Adigrat	Edagahamus	Wukro	Hawzen	Sinkata	Atsbi
Onset	Median	7-Jul	7-Jul	6-Jul	8-Jul	30-Jun	4-Jul	7-Jul
	Kendall's tau	-0.07	-0.10	-0.16	-0.06	-0.01	-0.18	0.07
	Slope	-0.10	-0.13	-0.29	-0.07	-0.05	-0.27	0.06
	P_{Value}	0.60	0.45	0.23	0.68	0.94	0.17	0.60
	SD (Days)	9	9	11	8	13	12	7
	CV%	5	5	6	4	7	6	4
Cessation	Median	22-Sep	20-Sep	11-Sep	21-Sep	25-Sep	20-Sep	23-Sep
	Kendall's tau	0.16	0.24	0.03	0.18	0.15	0.19	0.20
	Slope	0.14	0.13	0.00	0.20	0.15	0.13	0.30
	P_{Value}	0.23	0.09	0.85	0.17	0.25	0.15	0.13
	SD (Days)	6	7	3	7	7	6	9
	CV%	2	3	1	3	3	2	3
LGP	Median	74	72	68	74	85	77	78
	Kendall's tau	0.10	0.16	0.14	0.16	0.06	0.19	0.11
	Slope	0.25	0.35	0.29	0.33	0.20	0.50	0.25
	P_{Value}	0.44	0.24	0.30	0.22	0.68	0.15	0.40
	SD (Days)	11	11	12	11	14	13	11
	CV%	15	16	17	15	16	17	15
Dry Spell	Mean	26	24	30	23	26	27	29
	Kendall's tau	-0.10	-0.12	-0.25	-0.12	-0.06	-0.07	0.06
	Slope	-0.18	-0.11	-0.23	-0.16	-0.10	-0.08	0.08
	P_{Value}	0.47	0.35	0.06	0.38	0.65	0.59	0.67
	SD (Days)	11	8	7	9	10	10	10
	CV (%)	43	34	25	39	37	36	34

Conclusions

This study analyzed the variability and trends of rainfall, temperature and characteristics of crop growth season. Accordingly, the key findings of the study are:

1. Mean rainfall amount throughout the study area was found to be 550 mm/annum over the period 1980–2009. The contribution of *Kiremt* (Long rainy season) to the annual total rainfall amount estimated to be from 54–84%. Moreover, the contribution of the *Belg* (short rainy season) was not to be underestimated. In most of the stations it contributed to more than 25% of the total rainfall. Nevertheless, the CV of the *Kiremt* and *Belg* rainfall ranged from 21–31% and 37–45%, respectively indicating high variability of the seasonal total rainfall.
2. The individual Mankendall (MK-z) test statistics for monthly rainfall time series (June–September) exhibited increasing positive trend in all stations. The Sen's slope estimator indicated June (0.29–0.99 mm/month), July (0.27–2.51 mm/month), August (0.82–2.96 mm/month) and September (0.22–0.55 mm/month). Moreover, individual MK-z test for seasonal rainfall showed different trend directions. An increasing trend (0.8–5.51 mm/year) for annual, (2.34–6.78 mm/season) for *Kiremt* and decreasing trend (0.74–2.29 mm/season) for *Belg* rainfall totals. Similarly, the homogeneity trend test results for general case for the monthly rainfall experienced an overall increased trend during the study period in all stations ($\bar{Z}_{.}$= 1.44). The seasonal rainfall, however, experienced insignificant increased for annual rainfall (with $\bar{Z}_k$= 0.85) and significantly increasing for Kiremt ($\bar{Z}_k$= 1.59) and significantly decreasing for *Belg* season ($\bar{Z}_k$= -1.3).
3. The temperature trend increased significantly for both maximum and minimum temperature values (0.04–0.07 ^{o}C/year, 0.024–0.06 ^{o}C/year) and (0.07–0.1^{o}C/season, 0.06–0.12^{o}C/season) for annual and *Belg* in all stations, respectively. *Kiremt* season, however, showed both increasing and decreasing trend directions. In 5 of 7 stations the maximum temperature values showed an increasing trend while in 6 of 7 stations the minimum temperature showed decreasing trend. Similarly, the generalized case trend homogeneity test for temperature indicated that all seasonal maximum temperature trends indicating increased significant in each seasons while minimum temperature trend indicating increased for annual ($\bar{Z}_k$= 3.92) and *Belg* ($\bar{Z}_k$= 4.79), and decreased for *Kiremt* ($\bar{Z}_k$= -1.01).

4. The trend of growing season characteristics (onset, cessation, LGP and dry spell length did not change significantly over the study period (1980-2009) in all stations. In addition, the coefficient of variability of the onset (CV, <10%) and Cessation (CV, <5%) indicated very small, possibly relatively stable onset and cessation. However, the coefficient of variability of LGP was (CV, >15%) indicates unstable and how risky was crop production under rain-fed condition relying in one type of crop in the study area. Moreover, the CV of the dry spell length was (CV, >25%) this also showed the high risk of intra-seasonal water deficit situation in the study area.

   Overall, despite the significant increase trend of the rainfall in the main season (*Kiremt*), the high variability of rainfall amount was CV, >20% in the study area. In addition, the high variability of dry spell length of (CV, >25%) in association with short nature of LGP (68–85 days) and relatively variable (CV, >15%) had a negative impact on the agricultural activities of the study area during the study period (1980–2009). Hence, crop production in the study area demands appropriate adaptation strategies that considers the erratic nature of the rainfall, the long dry spell length in the season and increasing trend of temperature.

Abbreviation

CV: coefficient of variability; DD: Degree Decimal; DOY: Day of Year; ENACTS: Enhancing National Climate Services Initiative; LR: Linear regression test statistics; masl: meter above sea level; MK: Mankendall test statistics; NMA: National Meteorological Agency; NN: non-normal data; SD: Standard Deviation

Acknowledgment

The authors are thankful to the African Climate Change Adaptation Initiative (ACCAI–II B) project and to the Institute of climate and Society at Mekelle University for the financial support. We would also like to acknowledge to the National Meteorological Agency of Ethiopia for providing the weather data.

Authors' contributions

All the authors made a valuable contribution to this study. AGB has designed the study, collected and analyzed data, interpreted the results, and wrote the draft manuscript. SHM, GGA and AZA have participated in designing the study, analysis and interpretation, structuring the manuscript; and provided critical comments and suggestions on the draft manuscript. All authors read and approved the final manuscript.

Funding

The authors are thankful to the African Climate Change Adaptation Initiative (ACCAI–II B) project and to the Institute of climate and Society at Mekelle University for the financial support to undertake this study.

Availability of data and materials

The weather data used in the study were obtained from Ethiopian National Meteorological Agency (NMA). Access to the data can be obtained from NMA based on justifiable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

No potential conflict of interest was reported by the authors.

Author details

[1]Institute of Climate and Society (ICS), Mekelle University (MU), Ethiopia. [2]Land Resource Management Environmental Protection (LaRMEP), MU, Ethiopia. [3]LaRMEP, MU, Ethiopia. [4]ICS, MU, Ethiopia.

References

Abrha, MG (2015) Local climate trends and farmers' perceptions in southern Tigray, Northern Ethiopia. International Journal of Environment and Sustainability, 4(3)

Almazroui M, Balkhair KS, Islam MN, Şen Z (2017) Climate Change Impact on Monthly Precipitation Wet and Dry Spells in Arid Regions: Case Study over Wadi Al-Lith Basin. Advances in Meteorology, 2017

Aragie EA (2013) Climate change, growth, and poverty in Ethiopia, Texas Univ at Austin

Araya A, Stroosnijder L (2010) Effects of tied ridges and mulch on barley (Hordeum vulgare) rainwater use efficiency and production in Northern Ethiopia. Agricultural water management, 97(6):841-847

Araya A, Keesstra SD, Stroosnijder L (2010) A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia. Agricultural and forest meteorology, 150(7-8):1057-1064

Asfaw A, Simane B, Hassen A, Bantider A (2017) Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. Weather and Climate Extremes

Aura S, Muita R, Oloo P, Muchemi D, Kucera P, Mwangi S, Steinson M (2019) Intercomparison of tahmo, 3dpaws automatic weather stations and kmd's dagoretti corner, nairobi synoptic weather station data

Ayalew D, Tesfaye K, Mamo G, Yitaferu B, Bayu W (2012) Variability of rainfall and its current trend in Amhara region. Ethiopia Afr J Agric Res 7(10):475–1486

Belle G, Hughes JP (1984) Nonparametric tests for trend in water quality. Water resources research, 20(1):127-136

Berhe AA (2011) Coping with drought for food security in Tigray, Ethiopia

Bewket W, Conway D (2007) A note on the temporal and spatial variability of rainfall in the drought-prone Amhara region of Ethiopia. Int J Climatology 27(11):1467–1477

Chattopadhyay S, Edwards DR (2016) Long-term trend analysis of precipitation and air temperature for Kentucky, United States. Climate, 4(1): 10

Cheung WH, Senay GB, Singh A (2008) Trends and spatial distribution of annual and seasonal rainfall in Ethiopia. International Journal of Climatology: A Journal of the Royal Meteorological Society, 28(13):1723-1734

Conway D (2000) The climate and hydrology of the Upper Blue Nile River. Geographical Journal, 166(1): 49-62

De Lima MIP, Carvalho SCP, De Lima JLMP (2010) Investigating annual and monthly trends in precipitation structure: an overview across Portugal. Natural Hazards and Earth System Sciences, 10(11): 2429

Dinku T, Hailemariam K, Maidment R, Tarnavsky E, Connor S (2014) Combined use of satellite estimates and rain gauge observations to generate high-quality historical rainfall time series over Ethiopia. International Journal of Climatology, 34(7): 2489-2504

Dinku T, Funk C, Peterson P, Maidment R, Tadesse T, Gadain H, Ceccato P (2018) Validation of the CHIRPS satellite rainfall estimates over eastern of Africa. QJR Meteorol. Soc, 144: 292-312

Fiwa L, Vanuytrecht E, Wiyo KA, Raes D (2014). Effect of rainfall variability on the length of the crop growing period over the past three decades in central Malawi. Climate Research, 62(1): 45-58

Funk CC, Peterson PJ, Landsfeld MF, Pedreros DH, Verdin JP, Rowland JD, Verdin AP (2014) A quasi-global precipitation time series for drought monitoring. US Geological Survey data series, 832(4): 1-12

Gebre H, Kindie T, Girma M, Belay K (2013) Trend and variability of rainfall in Tigray, northern Ethiopia: analysis of meteorological data and farmers' perception. Academia Journal of Agricultural Research, 1(6): 088-100

Gebrehiwot T, van der Veen A, Maathuis (2011) Spatial and Temporal Assessment of Drought in the Northern Highlands of Ethiopia. Journal of Applied Earth Observation and Geoinformation 13: 309-321

Gebrehiwot T, van der Veen A (2013) Assessing the evidence of climate variability in the northern part of Ethiopia. Journal of Development and Agricultural Economics, 5(3): 104-119

Gebreselassie MG, Moges SA (2016) Spatial and temporal variability of dry spell lengths and indication of climate change in rainfall extremes at Tekeze River Basin, Ethiopia. International Journal of Water Resources and Environmental Engineering, 8(3): 39-51

Gan TY (1995) Trends in air temperature and precipitation for Canada and north-eastern USA. International Journal of Climatology, 15(10): 1115-1134

Hamza FM, Saimi FM Jaafar O (2017) Identifying the Monotonic Trend in Climate Change Parameter in Kluang and Senai, Johor, Malaysia. Sains Malaysiana, 46(10): 1735-1741

Hayelom B, Chen Y, Marsie Z, Negash M (2017) Temperature and precipitation trend analysis over the last 30 years in Southern Tigray Regional State, Ethiopia. Journal of Atmospheric Pollution, 5(1): 18-23

Jhajharia D, Dinpashoh Y, Kahya E, Choudhary RR, Singh VP (2014) Trends in temperature over Godavari river basin in southern peninsular India. International Journal of Climatology, 34(5): 1369-1384

Kendall M (1975) Rank Correlation Measures; Charles Griffin. London, 202p

Kiros G, Shetty A, Nandagiri L (2017) Extreme rainfall signatures under changing climate in semi-arid northern highlands of Ethiopia. Cogent Geoscience, 3(1): 1353719

Knapp KR, Ansari S, Bain CL, Bourassa MA, Dickinson MJ, Funk C, Kossin JP (2011) Globally gridded satellite observations for climate studies. Bulletin of the American Meteorological Society, 92(7): 893-907

Machiwal D, Jha MK (2008) Comparative evaluation of statistical tests for time series analysis: application to hydrological time series/Evaluation comparative de tests statistiques pour l'analyse de séries temporelles: application à des séries temporelles hydrologiques. *Hydrological Sciences Journal*, *53*(2): 353-366

Mann H (1945) Nonparametric Tests against Trend. Mantua, NJ, SR Hare, Y. Zhang, JM Wallace, and RC Francis (1997), Econometrics 13: 245-259

Meles K, Maria A, Tesfamichael N, Sunil S, Francis K, Lynne M (1997) Coping with low and erratic rainfall in the Eastern zone of Tigray, Ethiopia

Meze-Hausken E (2004) Contrasting climate variability and meteorological drought with perceived drought and climate change in northern Ethiopia. Climate research, 27(1):19-31

Muchuru S, Botai JO, Botai CM, Landman WA, Adeola AM (2016) Variability of rainfall over Lake Kariba catchment area in the Zambezi river basin, Z imbabwe. *Theoretical and applied climatology*, *124*(1-2):325-338

NMA (2007) Climate Change National Adaptation Programme of Action (Napa) Of Ethiopia. Addis Ababa, Ethiopia: The Federal Democratic Republic of Ethiopia Ministry of Water Resources, National Meteorological Agency

Palaniswami S, Muthiah K (2018). Change Point Detection and Trend Analysis of Rainfall and Temperature Series over the Vellar River Basin. Polish Journal of Environmental Studies, 27(4)

Parry M, Canziani OF, Palutikof J, van der Linden P, Hanson C (2007) Summary for policy makers. in: Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York: Cambridge University Press

Samo SR, Bhatti N, Saand A, Keerio MA, Bangwar DK (2017) Temporal Analysis of Temperature and Precipitation Trends in Shaheed Benazir Abad Sindh, Pakistan

Seleshi Y, Camberlin P (2006) Recent changes in dry spell and extreme rainfall events in Ethiopia. Theoretical and Applied Climatology, 83(1-4):181-191

Seleshi Y, Zanke U (2004) Recent changes in rainfall and rainy days in Ethiopia. International Journal of Climatology: A Journal of the Royal Meteorological Society, 24(8):973-983

Sen PK (1968) Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association 63:1379–1389

Sivakumar MVK (1992) Empirical analysis of dry spells for agricultural applications in West Africa. Journal of Climate, 5(5):532-539

Suryadi Y, Sugianto D N (2018) Climate Change In Indonesia (Case Study: Medan, Palembang, Semarang). In E3S Web of Conferences, 31:09-017

Tesfay GG, Yasir AM, Pieter van der Z, Amdom G, Gebremedhin G, Eyasu Y, Mulubirhan K (2019) Evaluation of multiple satellite rainfall products over the rugged topography of the Tekeze-Atbara basin in Ethiopia, International Journal of Remote Sensing, DOI: 10.1080/01431161.2018.1562585

Viste E, Korecha D, Sorteberg A (2012) Recent drought and precipitation tendencies in Ethiopia. Theor. Appl. Climatol. DOI 10.1007/s00704-012-0746-3

Weldesenbet GA (2019) Analysis of Rainfall Variability for Mekelle Meteorological Station, Northern Ethiopia (1960-2009)

Figures

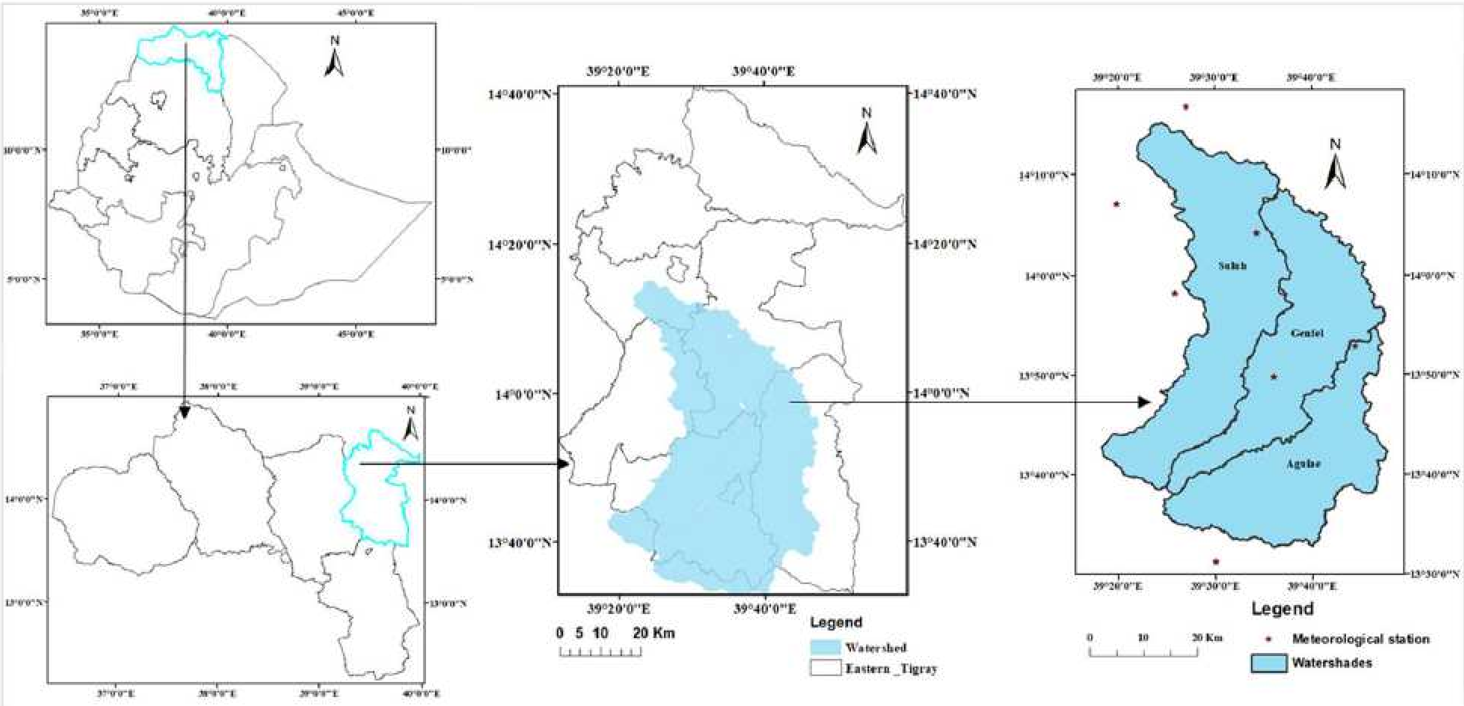

Figure 1

Location of the study area and selected watersheds Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.